large strips of lint soaked in tr. benzoin comp.; closed the wound with wire sutures; applied splints externally, and firmly bandaged the limb up to the shoulder. Sickness occurred after the operation—in my experience a rare occurrence when the anæsthetic is administered from Dr. Junker's inhaler—and repeatedly during the night. The patient remained almost pulseless, in spite of the application of heat to the surface, and of the administration of stimulants. Blood oozed sufficiently freely to stain all the dressings through, but not beyond this. During the following day there was no improvement; the patient was quite rational, able to talk, and fairly free from pain. The abdomen became much distended during the night, and vomiting occurred at intervals until the morning. Turpentine fomentations, enemata, and alkaline draughts gave no relief, the patient still remaining almost pulseless; heart beat regular; respiration much impeded by the abdominal distension; and the patient gradually sank, and died at 4.30 P. M., twenty-four hours after the operation.

The friends refused to allow a post-mortem examination.

ALLAHABAD, INDIA, December 5, 1883.

ARTICLE XII.

THE TIME REQUIRED BY THE BLOOD FOR MAKING ONE COMPLETE CIRCUIT OF THE BODY.[1] By ROBERT MEADE SMITH, M.D., Professor of Comparative Physiology, University of Pennsylvania.

IN a paper published in the *Philadelphia Medical Times* for January 26, 1884, I gave an account of a new method which I had employed to measure the amount of blood thrown out of the ventricles at each contraction, and to determine the time required by the blood for making one complete circuit of the body. I there had occasion to criticize the method which has heretofore been employed to answer this latter question, and to point out some of its defects. I have recently been studying this subject from another point of view, and have obtained some results which strengthen the position taken in the article referred to.

It will be remembered that the method which has been employed for this purpose, the infusion method of Hering (*Ztschrft. für Phys.* Bd. iii. and v., and *Arch. für phys. Heilkunde*, 1853, p. 112), consists in injecting into one jugular vein towards the heart a solution of some salt whose presence in the blood can be readily recognized by chemical tests, and in finding how soon after the injection the salt appears in the blood coming from the head in the corresponding vein on the opposite side of the neck.

When thus injected, to reach the peripheral portion of the opposite jugular vein, the salt must evidently have passed into the right heart, through the capillaries of the lungs, into the left heart, through the carotids or vertebral arteries to the head, and through the capillaries of the head or face to the jugular vein; or, in other words, must have passed through two capillary networks with their arteries and veins. It must, therefore, have completed an entire circulatory revolution. But to conclude that the time elapsing after the introduction of the salt into one jugular vein before it is found in the blood coming from the head in the opposite vein is the time required for one molecule of blood to pass from one of these points to the other, it must in the first place be admitted that the salt has been carried mechanically by the blood, without diffusing through it, with the same velocity as the blood itself; and in the second place to enable the formation of any opinion as to how often the entire mass of blood passes through the heart, it must be admitted that the velocity thus determined by the infusion method is the mean velocity of the blood mass. To show that both of these assumptions are unwarrantable is the object of the present communication.

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[1] Read before the College of Physicians of Philadelphia, March 5, 1884.

I. *The Element of Diffusion in Hering's Method.*—Poisseuille (*Ann. d. Sciences Nat.*, 1843, ii. ser. t. xix. p. 30) was the first, and as far as I know has been the only one to offer any experimental proof as to the falsity of the belief that the potassium salt was carried mechanically, as would be an inert body, by the blood. He repeated Hering's experiments on the horse, and was able to confirm his statement as to the time elapsing after the injection of the solution of potassium ferrocyanide before it appeared in the jugular vein of the opposite side; but he further found that this time was different for different substances, and was even modified by the presence of other substances when injected with the potassium ferrocyanide. Thus, while the time required for the circulation of the potassium ferrocyanide was *twenty-eight* seconds in the horse, when a little alcohol, in quantity insufficient to have any appreciable effect on the pulse and blood pressure as measured with the hæmadynamometer, was injected with the potash salt, the time of circulation was lengthened to *forty-five* seconds. Or, when potassium nitrate or ammonium acetate was administered under similar circumstances, the duration of circulation was reduced to *eighteen* or *twenty* seconds. In other words, he found that in the living body the rapidity of circulation of substances mixed with the blood agreed with the rapidity of flow of the same substances through dead capillaries or even through glass tubes.

It is, moreover, well known that if two fluids capable of mixing are brought into contact they will diffuse into each other with a considerable degree of rapidity, even when the mass of the liquid is at rest or when there is great difference in the relative volumes of the fluids; while if one fluid is poured into another with which it is miscible, or if agitated after the two fluids are brought into contact, diffusion is almost instantaneous. And as some force is always employed in injecting the salt solution into the vein, the mixture of this solution with the blood will be promoted, while the motion of the blood renders the conditions still more favourable for diffusion.

The assumption is, therefore, a fair one, until subjected to experimental disproof, that the element of diffusion forms a considerable item in the rapidity with which solutions of salts complete the circuit of the body. As far as I know, however, no such proof has ever been advanced, and the direct experiments which I have made on this subject serve rather to confirm than to disprove this assumption.

It is evident that if any particular, inert substance, small enough to pass through the capillary networks, and capable of ready recognition, could be injected into the blood, there could be no question as to the element of diffusion in the time required for such a substance to complete the circuit of the body; its velocity of movement must be the velocity of the current in which it moves; and if more time is required for the circulation of such a body than for the salt solution, it will be evident that some force other than the propulsion of the blood is concerned in the movement of the salt. These conditions I believe to be filled in employing pigeon's blood as the body whose transit is measured.

The red blood corpuscles of the pigeon have a short diameter smaller than the diameter of mammalian blood disks; and as all red blood corpuscles pass edgewise, and oval corpuscles (as in the frog) pass endwise in the centre of the blood stream, it is probable that the pigeon's corpuscles will circulate in mammalian bloodvessels with their long diameter in the axis of most rapid movement. They therefore agree with the first requisite as to size.

In the second place, they are oval and nucleated, and so form such a strong contrast to mammalian blood disks that a single pigeon's corpuscle in a drop of mammalian blood can be found under the microscope with the greatest readiness.

It might at first seem, however, that pigeon's blood injected into the vessels of a mammal is by no means an inert substance. It was proved in the earlier operations of transfusion that the blood of one species of animal is a direct poison for other species. When the blood, whether defibrinated or not, of one group of mammals is injected into the vessels of another of the same class but of different species, the corpuscles of the injected blood rapidly disappear, the plasma becoming red from the liberated hæmoglobin, which, when large quantities of blood are injected, may pass off through the kidneys, causing hæmoglobinuria, or even into the mucous and serous secretions; while at the same time the corpuscles of the animal receiving the injection, if they are themselves soluble in the injected blood, break down, and as a consequence convulsions and death through asphyxia may result.

The resistance offered to these phenomena differs in different groups of animals; thus, the dog, of all animals, is least liable to dangerous symptoms following the injection of blood from a different species. There is still another complication to be noted. Before the corpuscles are dissolved they tend to run together into heaps and so cause emboli, while again the liberation of hæmoglobin is likely to cause thrombosis.

It would seem from the above that pigeon's blood, which was also found by Bischoff to provoke analogous symptoms when injected into mammals, is by no means an inert substance, and is therefore entirely unfitted for the use I have made of it. Such is not, however, the case. The production of the symptoms mentioned above is a question of minutes; the duration of the circulation one of seconds; and I have found by direct experiment, as will be shown later, that the circulation is completed before disorganization commences.

There is one difficulty, however, that must be guarded against. The solution of the pigeon's corpuscles occurs not only in the vessels of the dog, the animal on which most of my experiments were made, but also after blood has been drawn and exposed to the air. Therefore, if the corpuscles are not sought for within a very short time after the withdrawal of the blood, they will only be found with great difficulty, and sometimes not at all, though it may be that their presence in the same portion of blood was proved only a few minutes before. To avoid error from this cause Dr. Gray, the Assistant Demonstrator of Histology in the University, kindly examined the blood for me the instant that the collection was made and before alteration had commenced. Such a procedure is not, however, absolutely necessary, as the first change in the corpuscles is their loss of hæmoglobin and consequent transparency, while the cell wall disappears still later, and the nucleus remains unchanged for some time. If, therefore, a little aniline red is added to the drop of blood under examination, pigeon's corpuscles, otherwise almost invisible, can be readily recognized.

Method of Experiment.—Two pigeons were killed by decapitation immediately before the experiment, and their blood collected in a dry porcelain dish and thoroughly defibrinated by whipping with glass rods; the blood was then filtered through a fine linen cloth moistened with half-per-cent. salt solution (water was avoided so as to preserve the corpuscles unaltered).

The animal to be experimented on was then tied and etherized, and glass canulæ, of the same calibre as the vessels, were inserted into the external jugular veins, in the left directed towards the heart, and in the right towards the periphery, flow of blood being prevented by spring clips. A canula was then inserted into the femoral artery and connected with a mercurial manometer writing on the kymographion.

The canula in the right external jugular vein was connected by means of a piece of rubber tubing about 4 centimetres long with a glass stopcock by which the outflow of blood could be regulated to about the amount normally passing through the vein.

The apparatus for collecting the blood and for noting the time of each collection consisted of a horizontal glass disk 31 centimetres in diameter, which could be uniformly rotated by clock-work at any desired speed. Twenty-four watch-glasses, each about 2 cm. in diameter, were fastened by sealing-wax around the edge of the disk, and the apparatus was so arranged that as the disk rotated the centre of each watch-glass passed under the stopcock connected with the right jugular vein.

The time was recorded in the following way: The entire disk, with the exception of the border on which the glasses were fastened, was covered with a layer of lampblack, and an electro-magnetic lever so arranged that as the disk revolved it would describe a concentric circle on the smoked surface. This electro-magnet, with a similar lever writing on the drum of the kymographion, was included in an electric circuit broken every second by a second's pendulum. Each interruption of the circuit, therefore, made a mark simultaneously on the revolving disk and on the moving paper of the kymographion. The apparatus was further so arranged that a single movement started the revolving disk and at the same time made a mark on the already revolving drum of the kymographion. The orifice of outflow from the stopcock and the time lever were on the same radius of the disk.

A syringe containing 10 c. c. was then filled with the defibrinated pigeon's blood and bound in the canula, previously filled with the same blood, in the left external jugular. After all connections were made the kymographion was started and allowed to revolve for twenty or thirty seconds before making the injection, so as to get a normal pulse and pressure curve. The clip was then removed from the right jugular vein, and as soon as the blood commenced to flow from the glass stopcock, the clip was removed from the left jugular, the injection made, and the disk started simultaneously; the instant of starting the disk being also automatically recorded below the pulse line on the kymographion.

When all the cups were filled with blood the disk was stopped and the blood instantly examined microscopically for the presence of pigeon's corpuscles. When it was determined in which glass they first appeared, it was only necessary to count the number of breaks in the time line on the disk from this glass to the start to determine how many seconds were required for the pigeon's corpuscles to pass from the left jugular vein to the right. While by laying off on the kymographion tracing the same number of seconds from the starting of the disk, the number of pulsations in that period was readily determined, and also whether the injection produced any disturbance of circulation.

The following are the details of two experiments made on this plan:—

Experiment I.—Nov. 24, 1883. Dog. Weight 18 kilo. Experiment conducted as described above; effects of ether had largely passed off before the experiment was made. Time required for pigeon's corpuscle to pass from the left to the right jugular 20 seconds. Pulse in 20 seconds = 55.

Before Injection.

Blood pressure.	Pulse in 15 seconds.	Respiration in 15 seconds.
160 mm.	36	6

After Injection.

Blood pressure.	Pulse in 15 seconds.	Respiration in 15 seconds.
5 seconds, 160 "		
10 " 155 "		
15 " 148 "	39 in first 15 seconds.	6
20 " 135 "		
30 " 90 "	43 in second 15 "	6
45 " 70 "	38 in third 15 "	7

The experiment was then interrupted for half an hour, when the low pressure produced by the pigeon's blood had passed off. 1 grm. of potassium ferrocyanide was then dissolved in 10 c. c. of normal salt solution, warmed to 38° C., and then injected into the left jugular vein, and the blood collected from the right jugular, and other details followed, as in the case of the injection of pigeon's blood.

Before Injection.

Blood pressure.	Pulse in 15 seconds.	Respiration in 15 seconds.
155	40	7

After Injection.

Blood pressure.	Pulse in 15 seconds.	Respiration in 15 seconds.
5 seconds, 110		
10 " 50		
15 " 30	16 in first 15 seconds.	1
20 " 20		
30 " 18	6 in second 15 " Dead.	none.

The blood was then allowed to stand in the watch-glasses until the serum separated; a drop of the latter was then drawn off with a pipette, placed on a porcelain dish, acidulated with dilute hydrochloric acid, and tested with a drop of dilute ferric chloride solution. It was then found that the portion of blood collected *fifteen* seconds after the injection of the potassium salt was the first to form the characteristic blue with the iron. The potassium ferrocyanide, therefore, passed from the left jugular vein to the right in *fifteen* seconds; pulse in 15 seconds = 16.

Experiment II.—Nov. 30, 1883. Dog. Weight 10 kilo. Details of experiment the same as in the preceding. The pigeon's corpuscles were found in 17 seconds; pulse in 17 seconds = 53.

Before Injection.

Blood pressure.	Pulse in 15 seconds.	Respiration in 15 seconds.
120	33	5

After Injection.

Blood pressure.	Pulse in 15 seconds.	Respiration in 15 seconds.
5 seconds, 120		
10 " 120		
15 " 120	44 in first 15 seconds.	6
20 " 120		
30 " 115		
60 " 60	50 in second 15 "	7

The animal was then allowed to remain undisturbed until the pressure again became normal, when 0.4 grm. potassium ferrocyanide, dissolved in 4 c. c. normal salt solution, was injected, and the blood collected as before.

Before Injection.

Blood pressure.	Pulse in 15 seconds.	Respiration in 15 seconds.
150	36	6

After Injection.

5 seconds,	120		
10 "	55		
15 "	25	18 in first 15 seconds.	2
30 "	15	15 in second 15 "	none.

Heart stopped one minute after injection.

The serum was then tested as in the previous case, and the Prussian blue found in the blood collected 9½ seconds after the injection of the potassium salt. The heart-beats in this period = 14.

The comparison of the times required in the same animal for the circulation of the pigeon's blood and the potassium salt clearly proves the falsity of the assumption that the salt moves through the vessels with the same velocity as the blood.

Vierordt (*Stromgeschwindigkeiten des Blutes*, Berlin, 1862), who, by his numerous experiments and important modifications and extensions of the plan of research, has identified himself with Hering's method, from a series of seventeen experiments made on dogs with an average body weight of 9.14 kilo. places the mean time of circulation in the dog at 15.22,″ and from experiments made on three rabbits of 1.37 kilo. average weight he gives 6.91″ as the mean time of circulation. In giving these figures he states that he has been careful to exclude all experiments in which the violent symptoms produced by the injection of the poison occurred within the time that his other experiments made on the same plan, but in which such symptoms did not appear, give as the mean time of circulation. This is, however, manifestly unwarrantable; for, were the substance injected a solid carried mechanically by the blood, any disturbance of circulation accompanied by great reduction in the pulse and blood pressure could only produce reduced velocity of the circulation, and consequently prolong the time required for the circuit of the injected solid around the bloodvessel system. But that in the face of such disturbance, and that, too, of the most violent character, the salt could be distributed with the greatest rapidity throughout the body clearly proves that it was not mechanically carried by the blood. Thus, in the experiments detailed above, we find that even when given in doses large enough to arrest the heart almost instantly, thus removing the main cause of the movement of the blood, and greatly reducing its velocity, we find, nevertheless, that the potash salt circulates more quickly even than the time given by Vierordt, and twenty-five per cent. faster than the pigeon's corpuscles are carried by the blood under normal conditions of pulse and pressure; for it should be noticed that the pulse and pressure remain comparatively undisturbed until after the circulation is complete. That the pigeon's cells are not delayed in their passage through the capillaries is proved by the fact that there is never any rise of blood pressure after making an injection of pigeon's blood, as would occur were there any blocking of the circulation in the capillaries.

The following are the results obtained in ten experiments made in the manner described above to determine the time required for the passage of the pigeon's corpuscles from one jugular vein to the other. In each case the pulse and pressure remained undisturbed until after the circuit was completed.

No.	Animal.	Time of circulation.	Pulse in time of circulation.	Weight.
1.	Dog . .	20 seconds.	55	18 kilo.
2.	" . .	17 "	53	10 "
3.	" . .	15 "	50	8 "
4.	" . .	15 "	47	8 "
5.	" . .	18 "	44	10 "
6.	Pup . .	20 "	60	3 "
	Averages	17.5 "	51.5	9.5 kilo.
1.	Rabbit . .	14 "		
2.	" . .	12 "	—	3 "
3.	" . .	9 "	27	1½ "
4.	" . .	9 "	35	2½ "
	Averages	11 "	31	2.3 "

It is seen, in the above series of experiments made on dogs with about the same average weight as those experimented on by Vierordt (9.41 kilo., and 9.5 kilo.), that the mean time required by the pigeon's corpuscles for the jugular circuit is 17.5″, as compared with 15.22″ obtained by Vierordt for the potassium salt; while in the rabbit 11″ was obtained as a mean as compared with 6.9″. Consequently, in the dog nearly 15 per cent. of the time stated by Vierordt as expressing the mean time, and in the rabbit over 59 per cent., are due to diffusion.

In this connection it might be suggested that the rapidity of circulation is greater in small animals than in large, not only on account of the shorter path to be traversed, as insisted upon by Vierordt, but because small animals contain, both absolutely and relatively as to body-weight, a smaller volume of blood; and since it has been shown that diffusion has something to do with the result, the salt will diffuse more rapidly into a small volume of fluid than into a large; therefore the element of diffusion is more marked in the rabbit than in the dog.

II. *The Value of the Infusion Method in Determining the Mean Time of Circulation.*—It may at the outset be admitted, with Hering and Vierordt, that the mean velocity of the circulation, if it could be determined for the jugular path, would probably express the mean time required for the total amount of blood to complete the circuit of the body. For while the portion of the blood which leaves the aorta to pass through the coronary arteries to reach the right auricle follows a shorter path than the blood which passes through the capillaries of the feet or the portal system, the velocity in the large trunks is so extremely high that the difference in time in passing through two large trunks, even of such extremes of length as the carotid at its origin and the metatarsal, is so slight as scarcely to be appreciated. The great part of the time of the circulation is therefore consumed in passing through the capillaries, and the jugular path may be regarded as giving a mean between the two extremes of distance above alluded to. It therefore only remains to determine whether the mean time required for the jugular circuit has been or can be obtained by the infusion method, or by the modification which I have employed.

It has already been shown that the elements of diffusion in this method cannot be neglected, since, even after stoppage of the heart, when the only remaining propelling force acting on the blood is the rapidly decreasing difference in pressure between the arterial and venous systems, the potassium salt is carried around the circuit even in less time than is stated by Vierordt to be the mean normal time of circulation, and in considerably shorter time than is required for the pigeon's corpuscles. But even this time required for the circulation of the pigeon's corpuscles is far above what must be the true mean time. For we know that in all cases of movement of fluids in tubes the portion of the fluid in the centre of the tube moves with a much higher velocity than the portions in contact with the walls of the tube. It is also known that the red blood corpuscles, from their greater specific gravity, are carried in this central column of greatest velocity, and, *a fortiori*, pigeon's corpuscles, having a greater specific gravity than non-nucleated mammalian cells, will have the maximum velocity of the moving column. Consequently, the time required for the circuit of the pigeon's corpuscles will be much shorter than that required for the mass of the blood.

An experiment of Schklarewsky (Hermann, *Handbuch der Physiologie*, vol. iv. p. 315) suggested to me a means by which the minimum velocity of the blood could be obtained. He found, when particles of different densities suspended in a fluid were propelled through capillary tubes, that the particles with the greatest density moved with the highest velocity, while the lighter particles moved in the peripheral portions of the stream where the velocity was the lowest. This fact serves to explain the motion of the red blood cells in the axis stream, while the lighter white blood corpuscles move along the walls of the vessels. If, therefore, a fluid containing suspended particles lighter than the red blood disks, and small enough to pass through the capillaries, is injected into the blood current, it may be assumed that the lighter particles will be thrown out of the more rapidly moving central current into the slower moving excentric layers.

The following experiment seems to indicate that this is actually the case:—

About 1 gram of carmine was rubbed up in a mortar with 30 c. c. of normal salt solution, poured into a conical glass vessel and allowed to stand for twenty-four hours; by this time all the larger carmine particles had settled to the bottom of the glass, and the upper layers, as proved by microscopic examination, contained only carmine granules, of which the largest were smaller than the mammalian red blood cells. This was determined by placing a drop of the carmine fluid with a drop of blood on a slide under the microscope. 10 c. c. of this fluid were then injected into the external jugular vein of a dog, and the time which elapsed before the carmine particles appeared in the blood drawn from the opposite jugular vein was determined in the same manner as was made use of in the experiments with the pigeon's blood.

The following are the details of the experiment:—

Experiment XI.—Dog. Weight 10 kilo.

Before Injection.

Pulse in 15 seconds.	Pressure.	Remarks.
35	110	
After Injection of 10 *c. c. of Carmine Fluid.*		
36 in first 15 seconds.	110	Carmine granules found in blood drawn from opposite jugular in 35 seconds after injection. Pulse in 35 seconds = 85.
36 in second 15 "	115	
37 in third 15 "	118	

Without laying too much stress on this single experiment, it is at any rate probable that a mean between this extreme and the maximum velocity shown by the pigeon's corpuscles will give the mean time of the circulation. Consequently, I would place the average time required to complete the circulation in a dog of 10 kilo. weight as between 25 and 30 seconds. It will be seen that this statement can be confirmed by another line of argument.

If the amount of blood driven out of the left ventricle was a constant quantity, the rapidity of the circulation would be in direct ratio to the number of pulsations of that organ. But as we know that the amount of blood thrown out of the heart at each contraction is subject to great variability, and as I have shown in the paper before alluded to, that this amount falls considerably below the estimate of the ventricular capacity made post-mortem, the attempt of Vierordt to formulate a law as to a definite relation between the duration of the circulation and the number of ventricular systoles which would agree with the numbers obtained by him as expressing the time of the circulation is not warranted by the facts in the case.

Thus, Vierordt stated that in all species of animals the time required for the completion of the circulation was the time required by the heart for making *twenty-seven* pulsations; consequently, each ventricular contraction must discharge $\frac{1}{27}$ of the entire bulk of blood in the body.

Now, according to the calculations of Heidenhain, which are generally accepted as correct, the average amount of blood in a dog is $\frac{1}{13}$ of his body's weight. A dog weighing 10 kilo. will, therefore, contain 769 grams of blood; or, as the specific gravity of blood is about 1050, 730 c. c. of blood. To propel this volume of blood once around the body in twenty-seven pulsations of the heart, at each contraction the ventricle must discharge 27 c. c. of blood, a quantity which is about double the amount which the ventricle of a dog weighing 10 kilo. can be made to contain.

There can be no doubt, however, though the statements of Vierordt in this connection are incorrect, that there must be a definite relation between the number of heart-beats and the time of circulation; for the application of the same line of argument to the data I have obtained gives a result which almost absolutely coincides with the figures obtained by direct measurement. In a dog weighing about 10 kilo., about 12 c.c. would be thrown out of the ventricle at each contraction under normal respiration; and as the amount of blood in the body would in a dog of this size be 730 c. c., sixty pulsations of the heart would be required to drive the entire amount once around the body. Placing the pulse-rate at 120 in the minute, the circulation would be completed in 30 seconds, a number which is identical with the figures given above.

It also appears that the number thus obtained by deduction as giving the number of heart-beats to complete the mean circulation is nearly in accordance with the number of pulsations required for the circulation of the pigeon's corpuscle; for if 50 pulsations are required for the maximum velocity and 85 for the minimum, the mean between these, 67, is near enough to the figure obtained by deduction to show that the method is nearly absolutely correct.

While there can be no doubt that an abnormal increase in the rate of the pulse, by diminishing the amount of blood thrown out of the ventricle, will lengthen the time required by the blood to complete the circuit of the body, it cannot be urged that in my series of experiments the pulse was sufficiently accelerated by the ether to cause any retardation of the circulation. For in Experiment I., where the effect of the ether had passed off before the estimate was made, the time of circulation was even longer than in cases in which the narcosis was more profound.

There is one other point in which my experiments fail to confirm the results obtained by Vierordt. Although I cannot find in his paper before referred to any experiments to substantiate the assertion, he makes the statement (*Grundriss der Physiologie des Menschen*, 5th Auflage, 1877, S. 162) that moderate stimulation of the vagi lengthens the time of circulation by reducing the number of pulsations of the heart, but that nevertheless 26 contractions are here also required to complete the circuit; from which he makes the deduction that moderate irritation of the vagus reduces the number of the heart's contractions without modifying the amount of blood thrown out at each systole.

Of course, since I have not seen the details of the experiments on which these conclusions are based, it is impossible to form any opinion as to what is meant by "moderate" stimulation of the vagus.

As far as I know, no measurements of the quantity of blood thrown out from the heart during vagus irritation have ever been made, though a diminution of pulse rate by cold has been found by Howell and Donaldson (*Proc. Roy. Soc.*, No. 226, 1883) to augment the quantity of blood discharged at each systole. And if the irritation were not sufficiently severe to cause much reduction in blood pressure or velocity it is conceivable that the pulse might be considerably reduced in frequency, but that the reduction would be balanced by the larger volume of blood discharged at each contraction. The only difference, therefore, in the phenomena of circulation during vagus irritation from the normal condition would be that fewer heart beats would be required to complete the circulation. The following experiments show this to be the case:—

Experiment XII.—Dec. 18, 1883. Dog. Weight 11 kilo. Pigeon's blood injected, and time of circulation estimated as before. Irritation of vagus with induction current commenced at moment of injection.

Before Injection.

Pressure.	Pulse in 15 seconds.	Respiration.	Remarks.
180 mm.	37	5	

After Injection and Vagus Irritation.

140 "	16 in first 15 seconds.		Vagus irritated 31 seconds. Corpuscle found in 19 seconds. Pulse in 19 seconds = 21; normal pulse in 19 seconds = 50.
150 "	20 in second 15 "		
140 "	32 in third 15 "		
120 "	48 in fourth 15 "		

Experiment XIII.—Dec. 20, 1883. Dog. Weight 14 kilo. Conditions of experiment the same as in preceding.

Before Injection.

Pressure.	Pulse in 15 seconds.	Respiration.	Remarks.
160	35	7	

After Injection and Irritation.

140	18 in first 15 seconds.		Vagus irritated 44 seconds. Corpuscle found in 14 seconds. Pulse in 14 seconds = 17. Normal pulse in 15 seconds = 35.
160	24 in second 15 "		
130	30 in third 15 "		
90	47 in fourth 15 "		

UNIVERSITY OF PENNSYLVANIA,
February, 1884.

ARTICLE XIII.

MULTIPLE GUNSHOT WOUNDS, WITH CONSEQUENTIAL REFLEX PHENOMENA ON THE PART OF THE EYE, HEART, AND LEG.

By D. S. LAMB, A.M., M.D., Army Medical Museum, and SWAN M. BURNETT, M.D., Professor of Clinical Ophthalmology and Otology in the University of Georgetown, and Ophthalmic and Aural Surgeon to the Central Dispensary and Emergency Hospital, Washington.

IN the third surgical volume of the *Medical and Surgical History of the War*, page 748, is the report of a case (Case 1090) of reflex paralysis in consequence of, but occurring twenty years after, a gunshot wound.